NCP-7 Lithium-Ion Cell Life Test Performance

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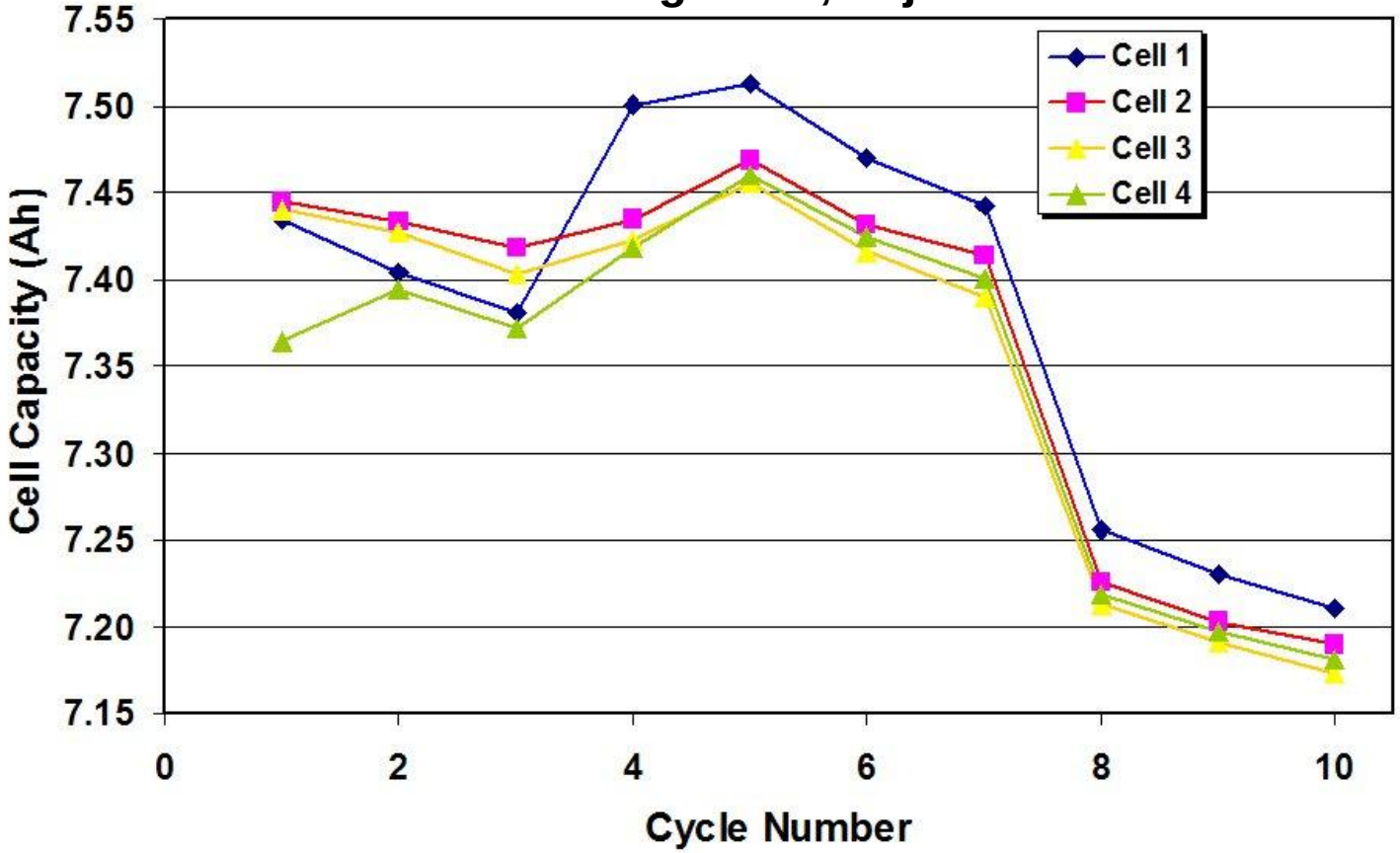
Background of NCP-7 Cell Life Tests

- **Test concepts developed in early 2000**
  - ***Feasibility test for space use of Yardney Li-ion cells***
    - **Various real time and accelerated feasibility life tests have been run on 17 different types of Li-ion cells since 2000**
  - ***Space Li-ion technology new at the time***
  - ***Cycle life compared directly with other Li-ion, NiCd and NiMH cells***
- **Tests were run between 5 and10ºC**
  - ***Low temperature electrolyte in cells, similar to MER cells used by JPL***
  - ***Belief at the time that low temperature operation would give improved cycle life***
- **Four cells delivered by Yardney in early 2001**
  - ***Cells activated in December of 2000***
  - ***Acceptance testing completed in January of 2001***
- **Life testing began in June 2001**
  - ***15 and 16-cycles/day profiles between 20% and 25% depth of discharge****
  - ***Peak charge voltage kept below 4.0 to hopefully maximize life***

***All depths of discharge are based on 7 Ah nameplate capacity**

Beginning of Life Cell Capacities

- Measured in January 2001, discharge to 2.7 volts
- Showed a decreasing trend, to just over 7 Ah



Two Life Tests are Being Run – Two Cells Each

- **Fixed DOD Test**
  - ***90 minute cycle***
  - ***16 cycles per day***
  - ***21.4% DOD***
  - ***No operational capacity measurements during cycling***
- **Variable DOD Test**
  - ***96 minute cycle***
  - ***15 cycles per day***
  - ***14.3% to 24.8% DOD***
  - ***No operational capacity measurements during cycling***
- **All four cells in both tests continue to cycle with good performance**

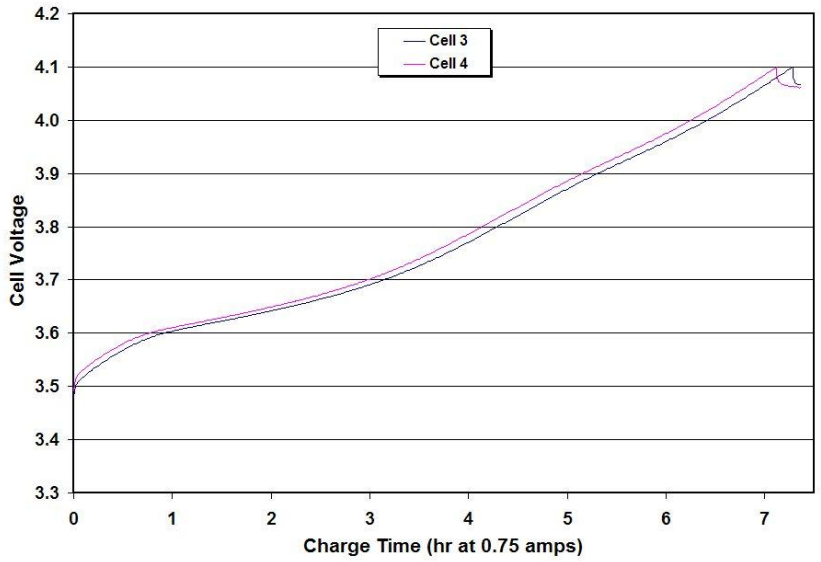
Fixed Depth of Discharge Test (cells 1 & 2)

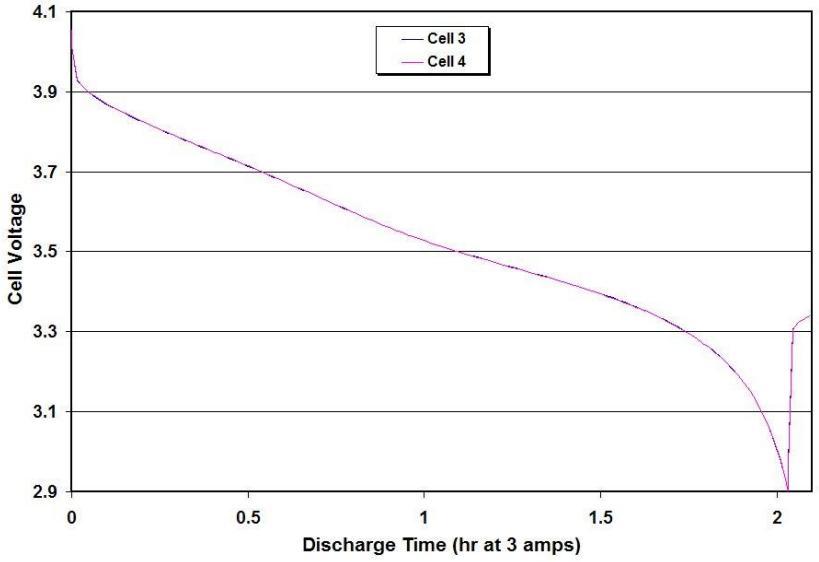
- **Two cells tested with 1.5 Ah discharge each cycle**
  - ***30-minute discharge, 3 amp discharge rate***
  - ***21.4% depth-of-discharge (DOD) every cycle***
  - ***Cycle life compared directly with other Li-ion, NiCd and NiMH cells***
- **Recharge is to 4.0 volts**
  - ***60-minute recharge time each cycle***
  - ***Charge at 2.25 amps to maximum voltage, then 0.83 amps until a desired recharge ratio was attained***
  - ***Recharge ratio was adjusted to enable voltage to just reach 4.0 at the 0.83 amp rate***
  - ***Cells operated in series with commercial NiCd and NiMH cells*, which required recharge ratio control***
- **Test interrupted after ~ 34,000 cycles**
  - ***Tab welds on terminal posts loosened***
  - ***Cells connections changed to compression contacts on terminal posts***
- **Test continues to operate at ~59,000 cycles**

*NiMH cells continue to operate, NiCd cells failed after 20,000 to 25,000 cycles

Fixed Depth of Discharge Test – Initial Capacity

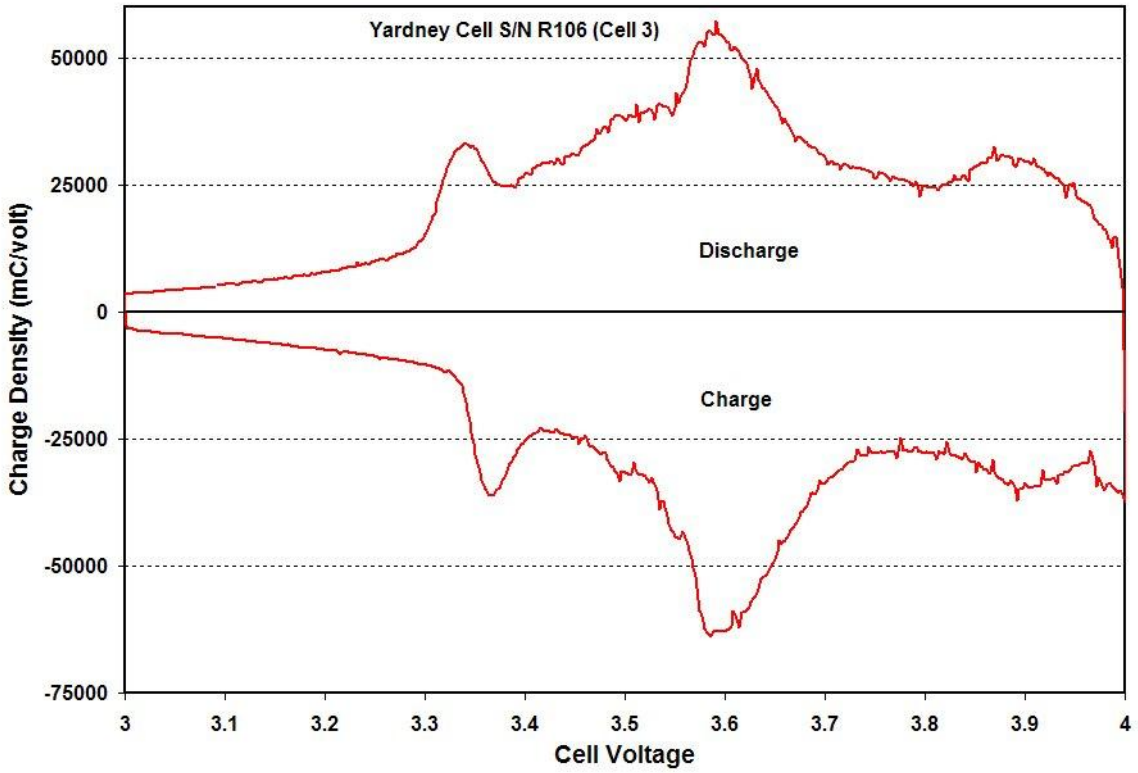
- Measured in June 2001, showed capacity of 6.08 Ah to 2.9 volts
- Lower than the capacity in January 2001
- Life test cycling initiated in June 2001





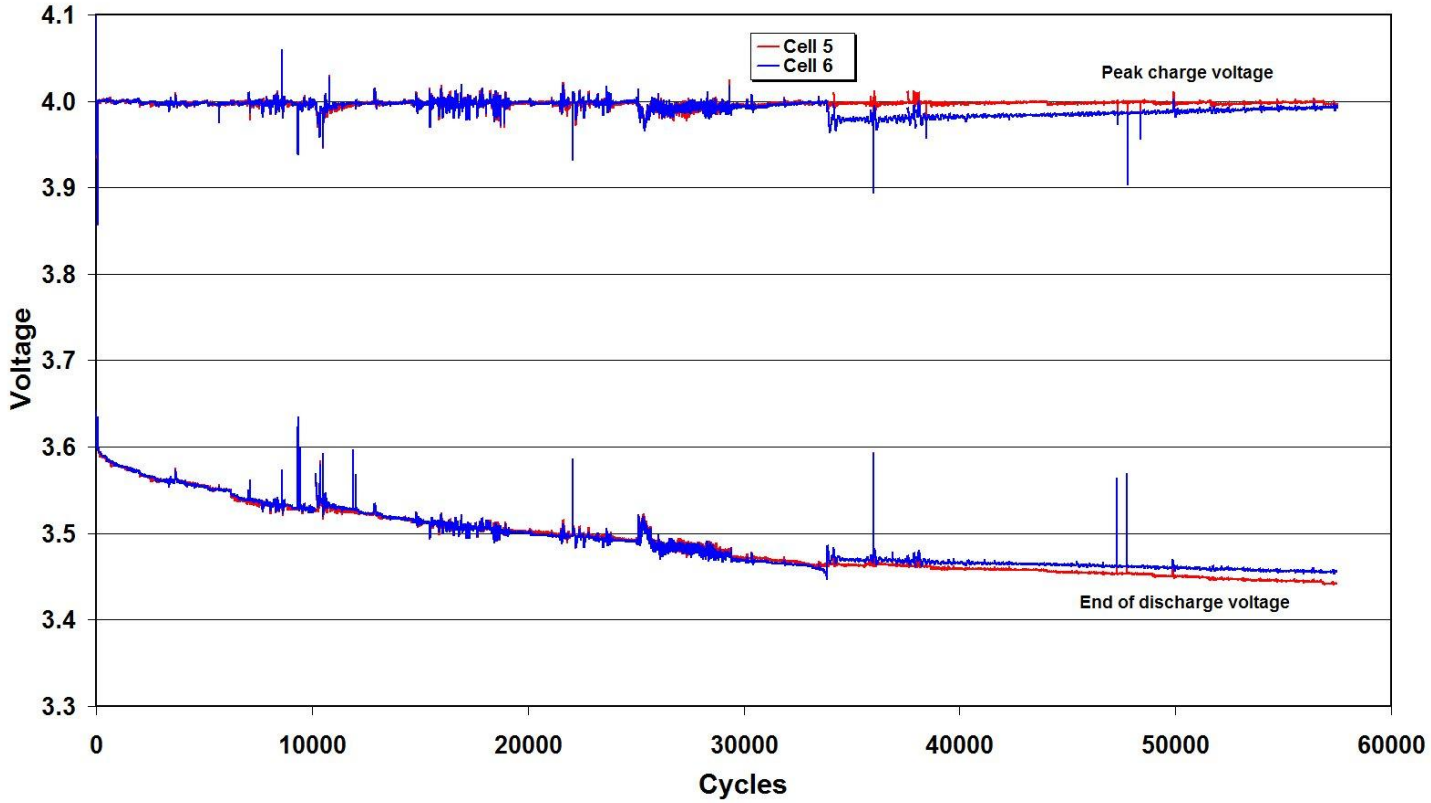
Fixed Depth of Discharge Test – BOL Testing

- Electrochemical Voltage Spectroscopy performed on one cell
- Measured charge density vs. voltage under near-equilibrium conditions



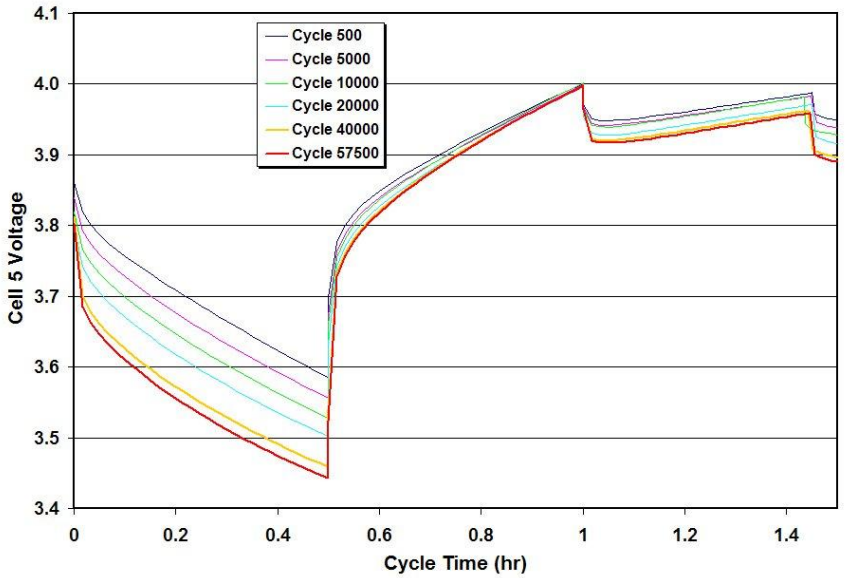
Fixed Depth of Discharge Test – End of Discharge and Peak Charge Voltages

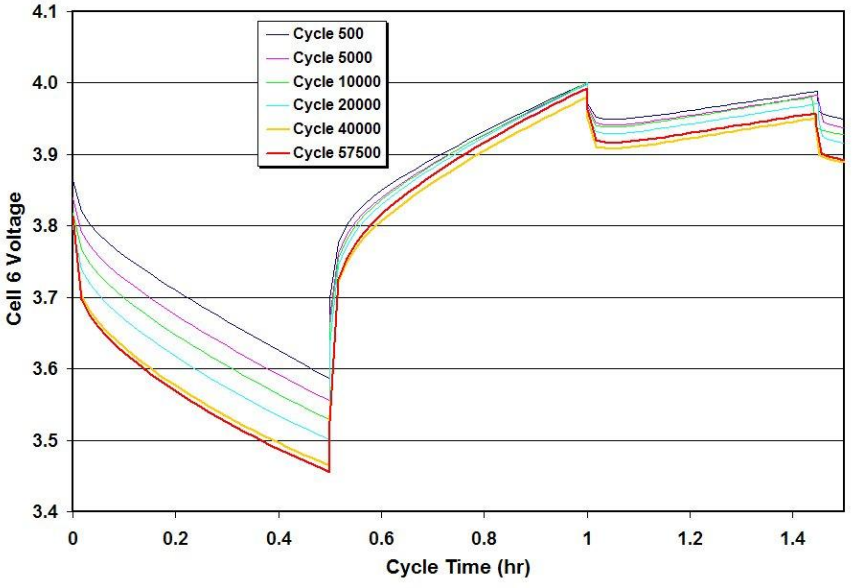
- Continuing stable performance



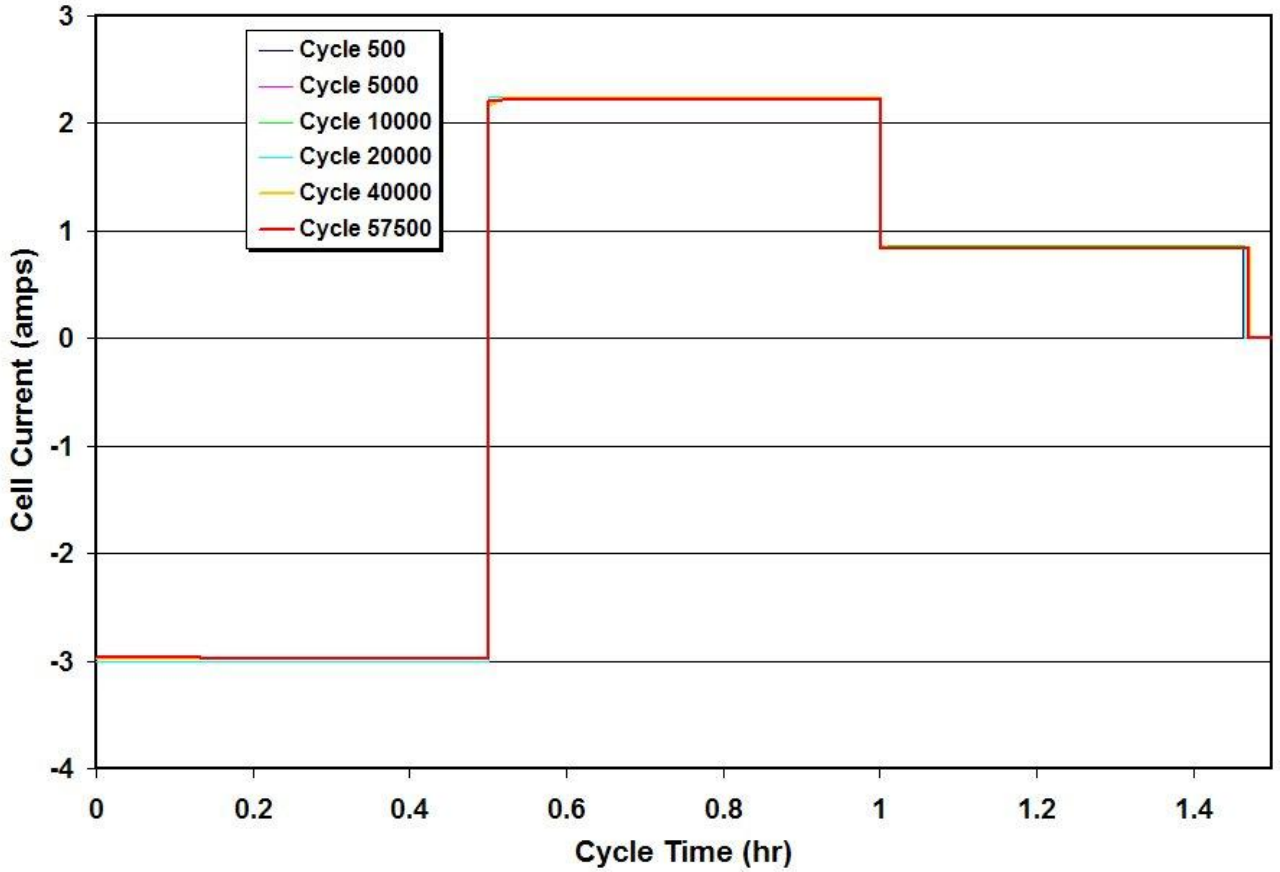
Fixed Depth of Discharge Test – Charge and Discharge Voltage for Selected Cycles

- 21.4% DOD
- Two step recharge, with several minutes of open circuit at the end after the required recharge ratio has been reached

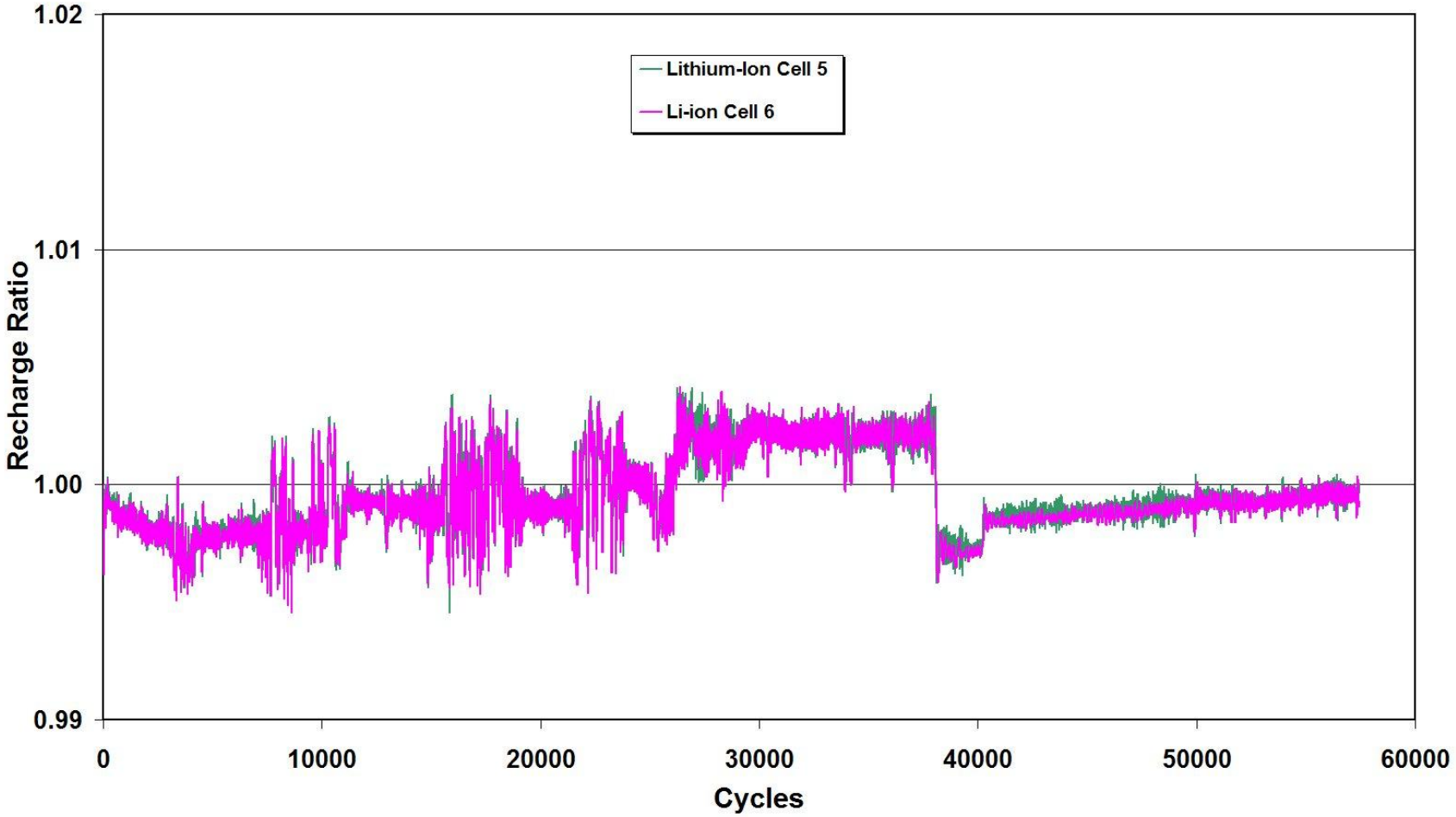




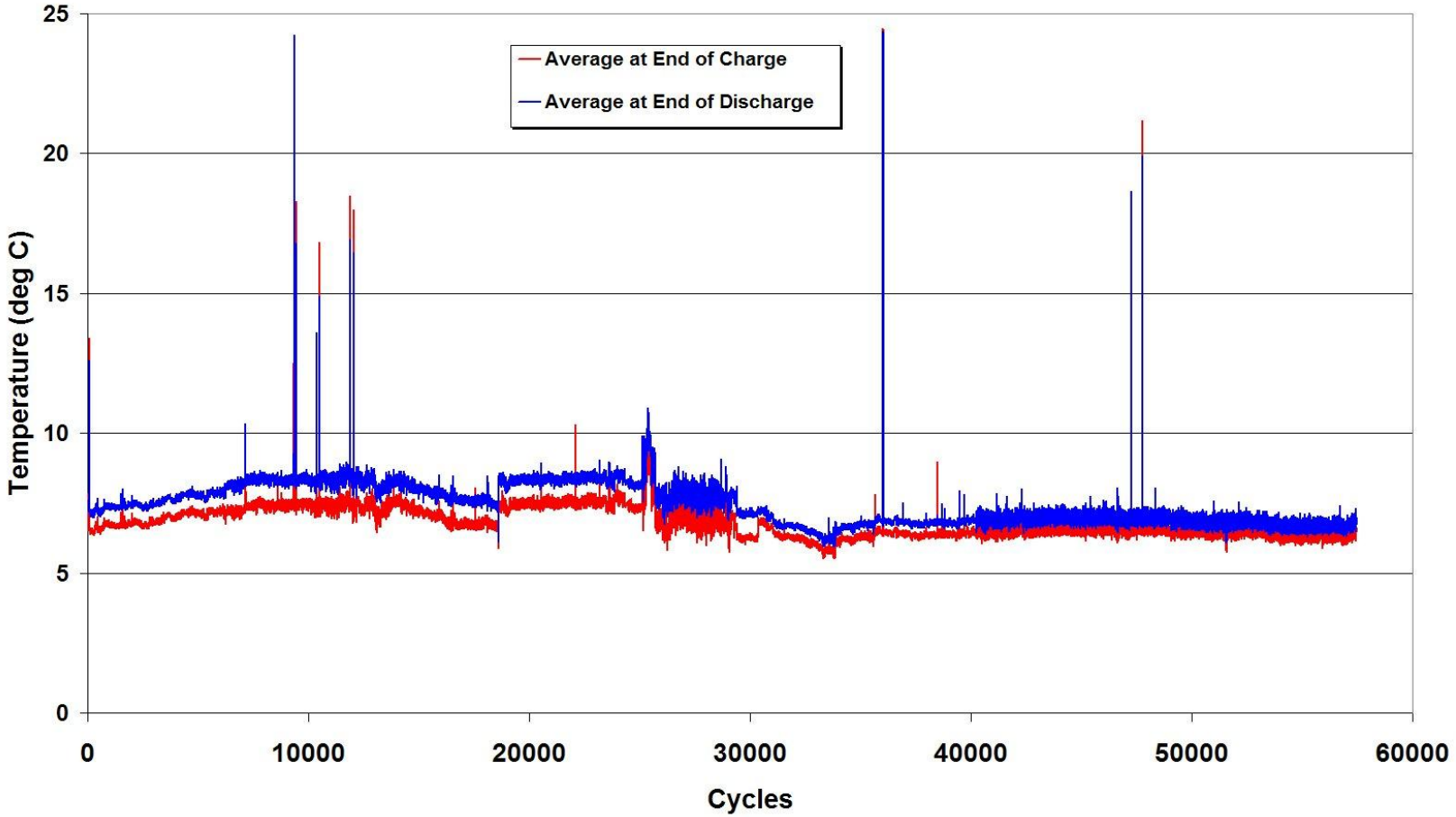
Fixed Depth of Discharge Test – Charge and Discharge Current Profiles for Selected Cycles



Fixed Depth of Discharge Test – Recharge Ratio



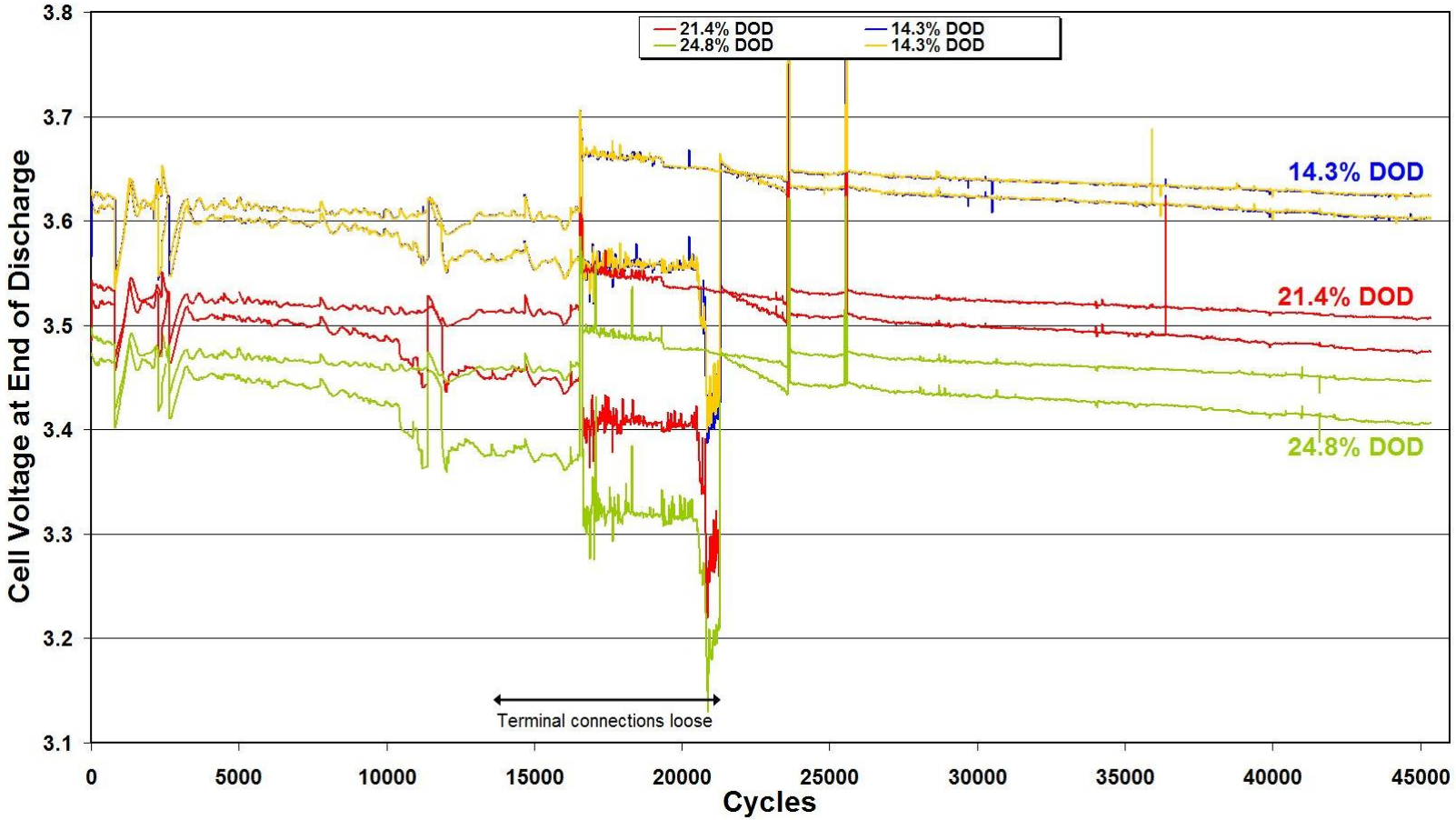
Fixed Depth of Discharge Test – Temperature



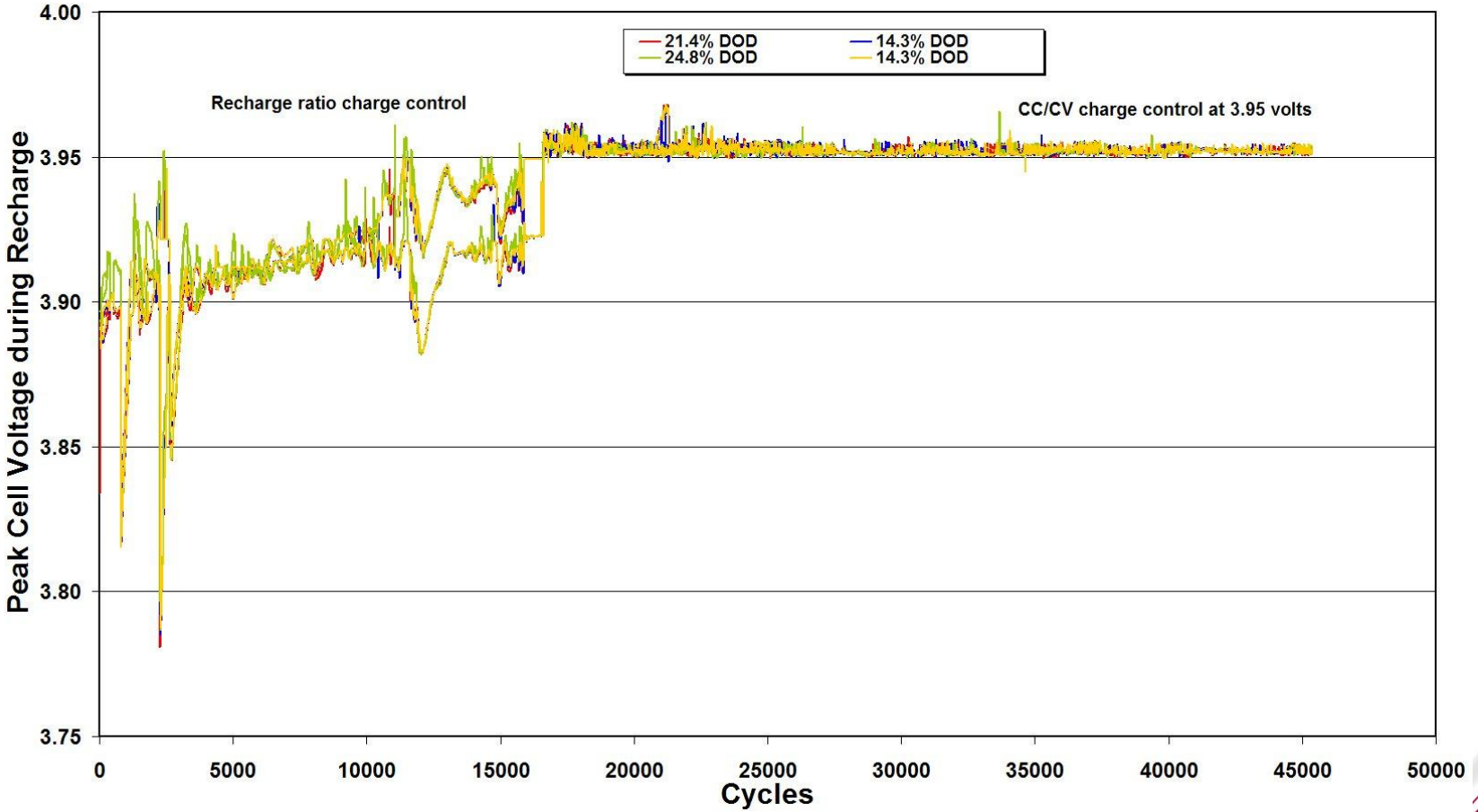
Variable Depth of Discharge Test (cells 3 & 4)

- **Two cells tested using three depths of discharge each day**
  - ***34-minute discharge, 15 cycles per day***
  - ***Daily 7 cycles at 14.3% DOD (1.765 amp discharge rate)***
  - ***Daily 7 cycles at 21.5% DOD (2.647 amp discharge rate)***
  - ***Daily 1 cycle at 24.8% DOD (3 amps for 30 min, 3.5 amps for 4 min)***
- **Recharge is nominally to 3.95 volts**
  - ***62-minute recharge time each cycle***
  - ***First 16,500 cycles used recharge ratio charge control***
    - **Charge at 2.25 amps (2.5 amps for higher DOD) to maximum voltage, then taper current until the desired recharge ratio attained**
  - ***Subsequent cycles used constant current at either 2.25 or 2.5 amps, with current taper to hold each cell at 3.95 volts (CC/CV)***
- **Test interrupted after ~ 21,500 cycles**
  - ***Tab welds on terminal posts loosened***
  - ***Cells connections changed to compression contacts on terminal posts***
- **Test continues to operate at ~46,000 cycles**

Variable Depth of Discharge Test – End of Discharge Voltage

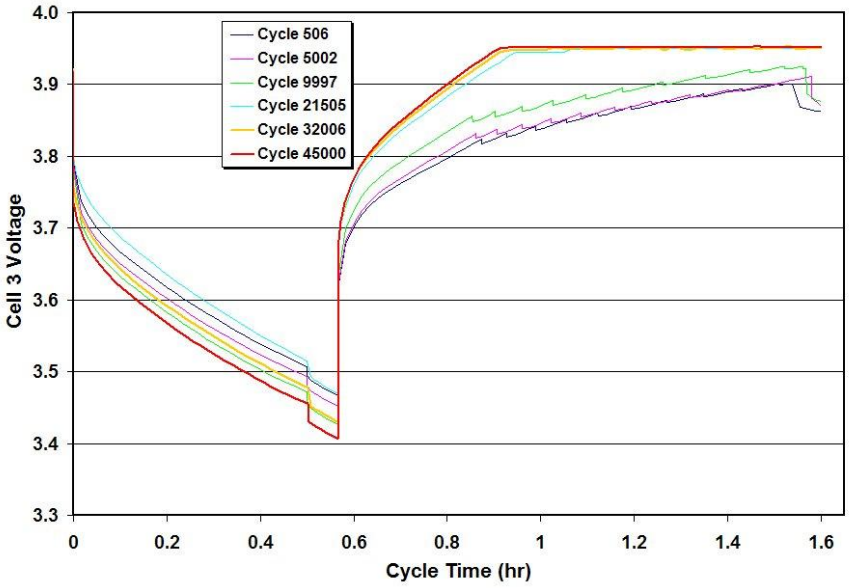


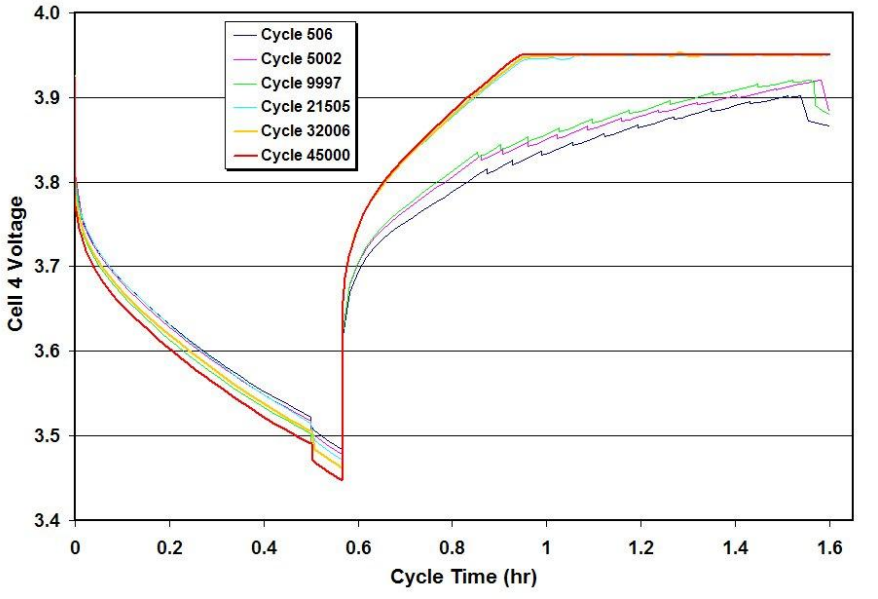
Variable Depth of Discharge Test – Peak Charge Voltage



Variable Depth of Discharge Test – Voltages for Selected Cycles at Maximum 24.8% DOD

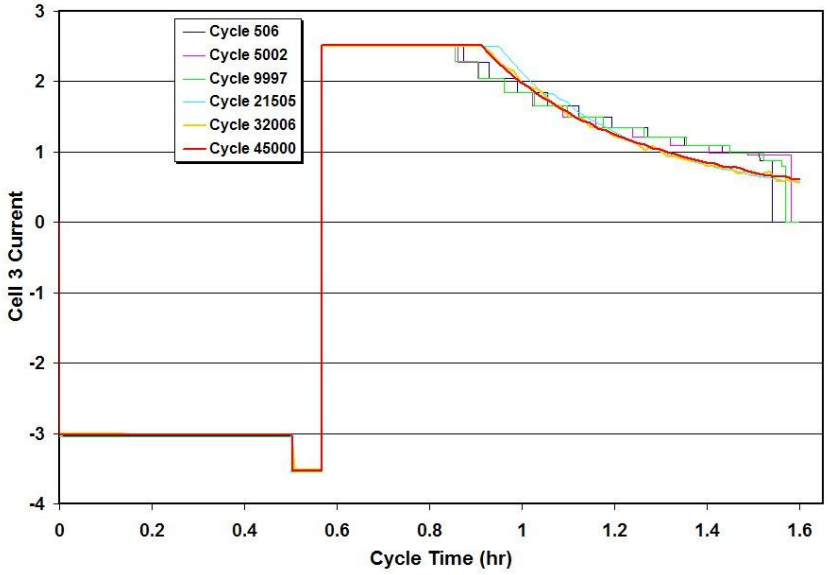
- Recharge ratio charge control with stepwise current taper for first 16,500 cycles
- CC/CV charge control at 3.95 volts peak thereafter

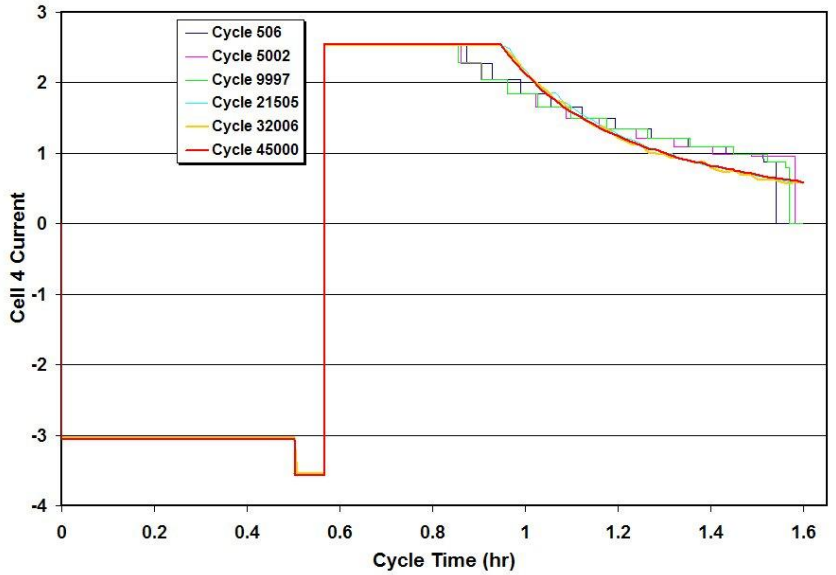




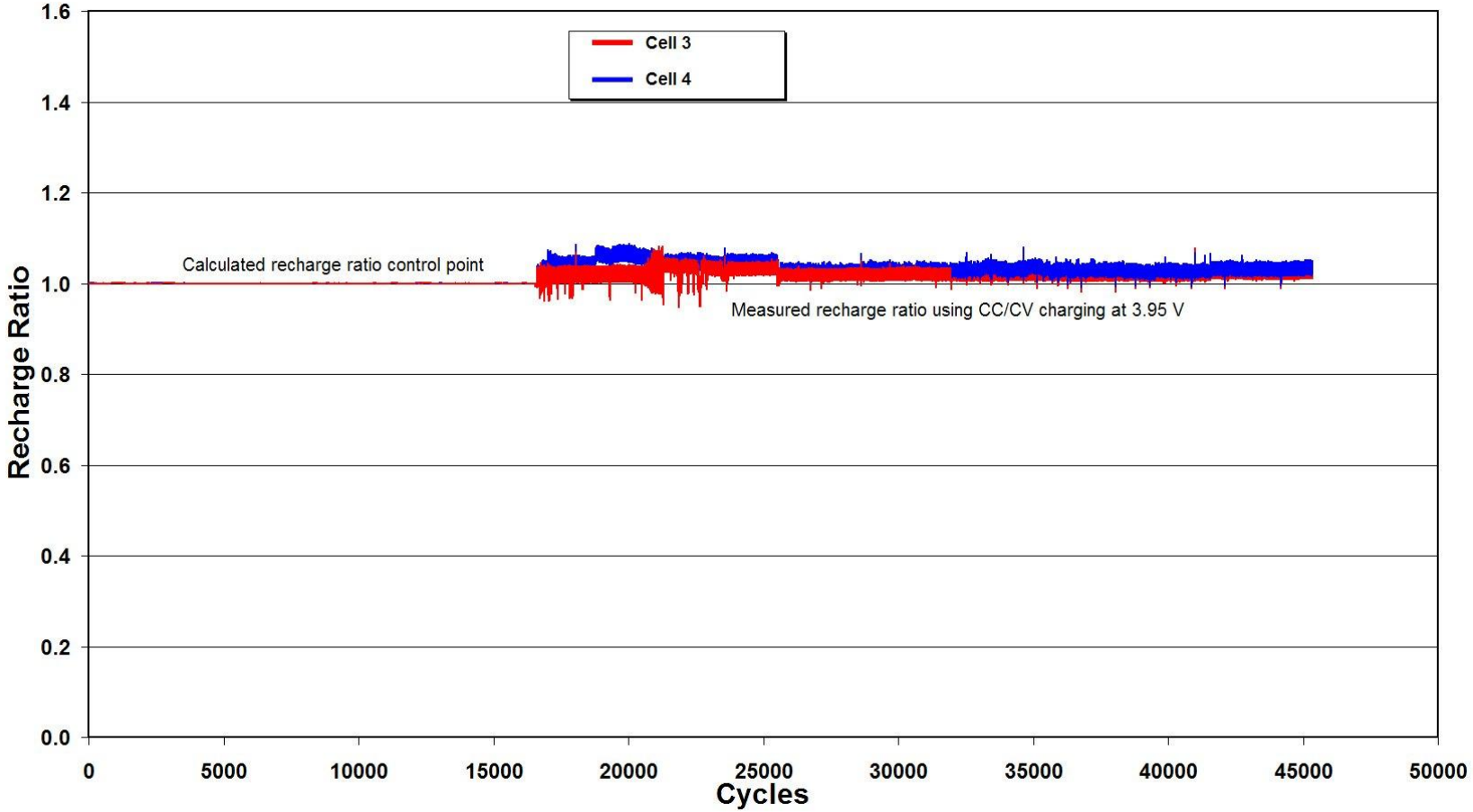
Variable Depth of Discharge Test – Currents for Selected Cycles at Maximum 24.8% DOD

- Recharge ratio charge control with stepwise current taper for first 16,500 cycles
- CC/CV charge control with real current taper at 3.95 volts peak thereafter

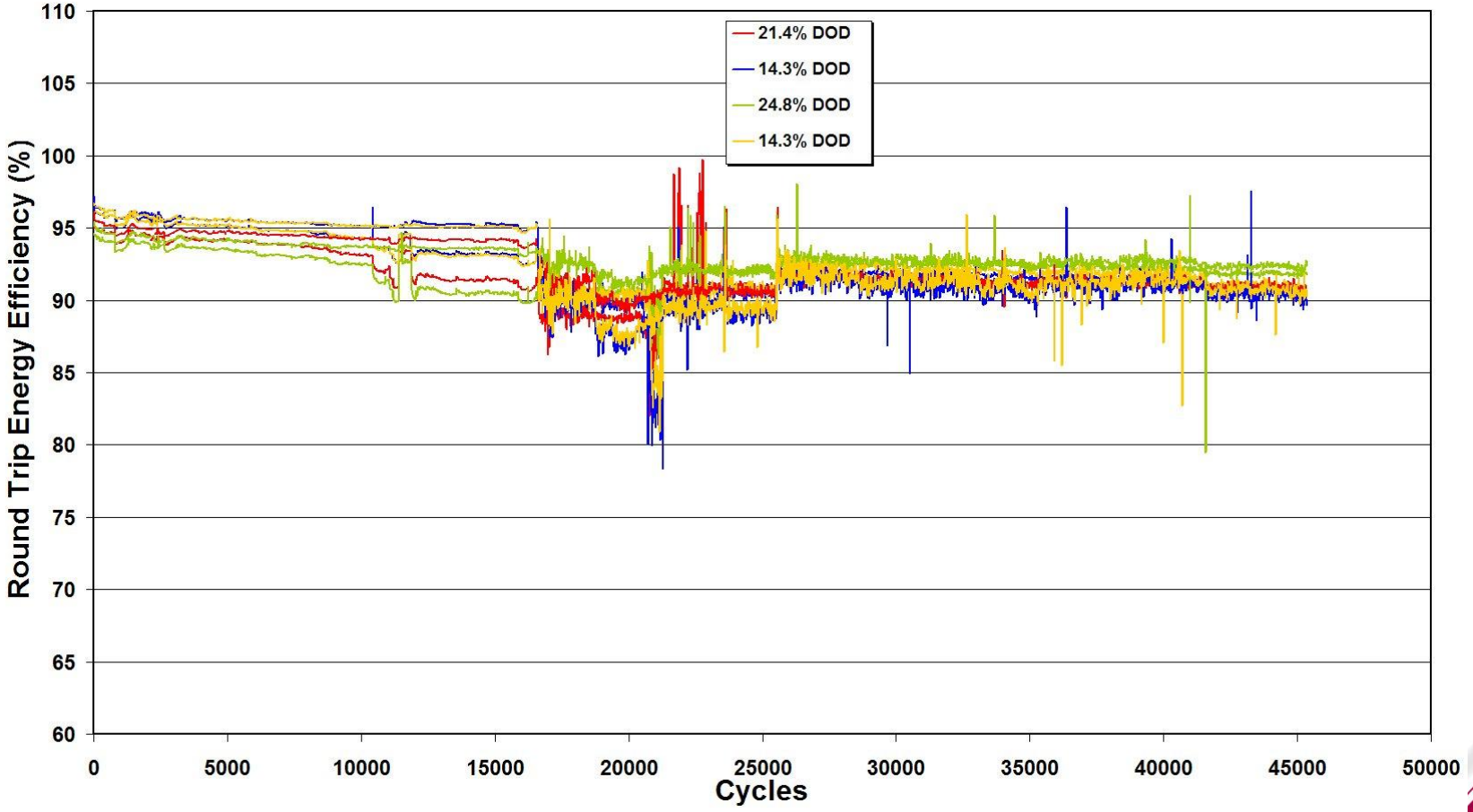




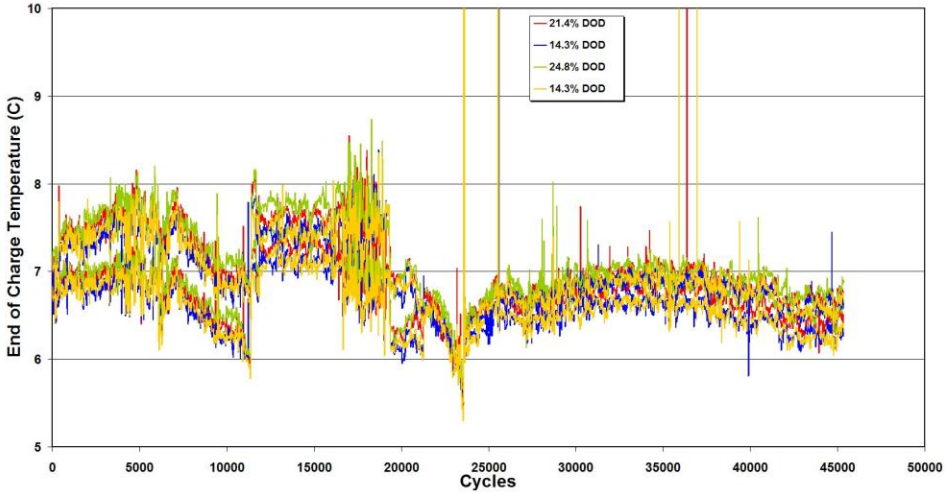
Variable Depth of Discharge Test – Recharge Ratio



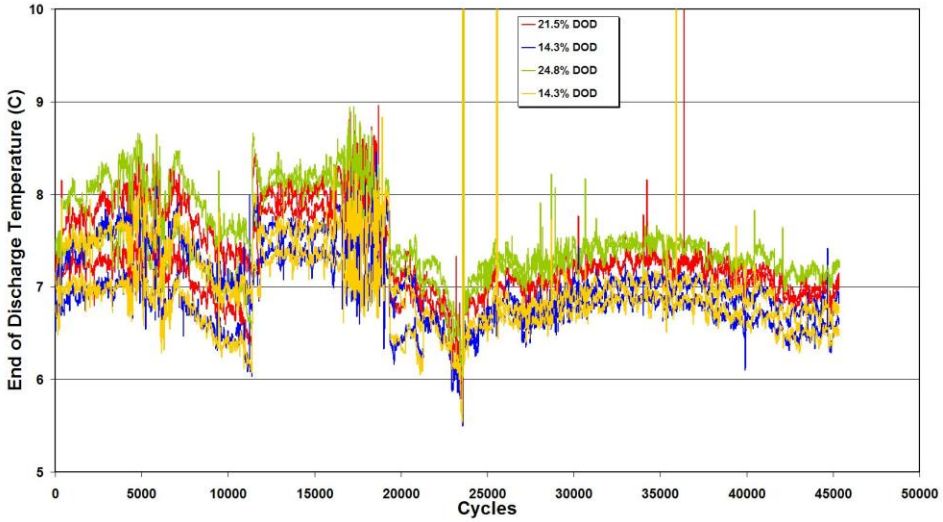
Variable Depth of Discharge Test – Cyclic Energy Efficiency



Variable Depth of Discharge Test – Temperature



End of Charge Temperature



End of Discharge Temperature

Conclusions

- **The Yardney NCP-7 cells have performed well for over 10.5 years**
  - ***Good performance for up to ~58,000 cycles***
  - ***Performance trend shows gradual continuing degradation***
- **NCP-7 cells are no longer available**
  - ***NC cathode active material obsolete***
  - ***MCMB anode material also obsolete***
- **Generic feasibility demonstrated for long term space use**
- **Life test planned to continue until cells fail**

Acknowledgement

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